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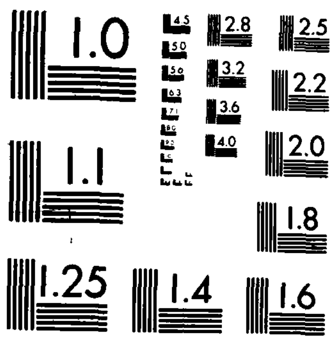
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An approach to the automated extraction of cultural terrain features from remotely sensed imagery is the development of structuring elements that are based on the concepts of digital morphology. The image structures of cultural terrain features show a great deal of regularity and can be represented by models. Operators that measure and analyze image structures provide effective tools for the automated feature extraction process. Morphological operations that belong to the class of hit-or-miss transforms are discussed in some detail. The operations of dilation and erosion are explained and demonstrated on radar imagery. An operation that combines gray-tone differencing and thresholding is used for extracting a road segment from an image. The future applications of digital morphology for analyzing and measuring image primitives, attributes, descriptors and descriptor sets of terrain features in support of automated feature extraction are briefly discussed.

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ANALYSIS OF REMOTELY SENSED IMAGERY USING DIGITAL MORPHOLOGY

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BIOGRAPHICAL SKETCH

Dr. Rohde is currently a supervisory physicist and team leader of the Center for Automated Image Analysis, U.S. Army Engineer Topographic Laboratories (USAETL). Other assignments included Working Group Leader of the USAETL's Defense Navigation Satellite Systems Division and the NAVSTAR Global Positioning System, and Chief of the Electronic Satellite Tracking Division, U.S. Army Map Service. Dr. Rohde received his bachelor's degree in physics from the University of Gottingen in 1943, his master's degree in physics from the University of Marburg in 1947 and his doctorate in physics from the University of Giessen in 1953.

ABSTRACT

An approach to the automated extraction of cultural terrain features from remotely sensed imagery is the development of structuring elements that are based on the concepts of digital morphology. The image structures of cultural terrain features show a great deal of regularity and can be represented by models. Operators that measure and analyze image structures provide effective tools for the automated feature extraction process. Morphological operations that belong to the class of hit-or-miss transforms are discussed in some detail. The operations of dilation and erosion are explained and demonstrated on radar imagery. An operation that combines gray-tone differencing and thresholding is used for extracting a road segment from an image. The future applications of digital morphology for analyzing and measuring image primitives, attributes, descriptors and descriptor sets of terrain features in support of automated feature extraction are briefly discussed.

INTRODUCTION

A vitally important problem facing the Department of Defense is the ability to quickly and efficiently analyze remotely sensed image data. Modern remote sensing systems are capable of collecting large amounts of image data so that timely and efficient manual analysis becomes a problem. Thus, there is a need for the development of automated image analysis and feature extraction capabilities to speed up the analysis process. The Center for Automated Image Analysis of the U.S. Army Engineer Topographic Laboratories is tasked with the development of methods and techniques for automated feature extraction from all-source imagery.

DEFINITIONS AND ELEMENTS OF MORPHOLOGY

An image in the digital domain consists of an array of pixels. Each pixel of a black and white image is associated with a digitized gray-tone value. The pixels of color images also include the digitized components of the primary colors. The human visual system of an image analyst is trained to recognize, understand, and extract features from

the image [6]. This process is accomplished by mentally analyzing the pixel structure of the image. For automated image analysis the mental processes have to be replaced by algorithms that are executed on computers. In digital morphology the image is represented as a discrete set or a combination of sets. The elements of the image set are normally treated as subsets of the image set and include the array coordinates and digitized gray-tone values as elements. Any morphological operation is defined as a mapping or transformation T of one set X (the image set) into another set Y (the transformed set), followed by a measure m.

The notations for morphological operations are expressed in terms of notations generally used in set theory, logic and topology. Because these notations are not commonly known, the morphological operations presented in this paper are explained and discussed by using examples rather than mathematical expressions.

A morphological operation is normally executed as follows: the image or the feature of the image is considered as the set X. The operator that is used in the execution of the operation is called the structuring element S, and is represented by a set in the form of an array. The origin of the structuring element can be indicated by pointers. An algorithm that defines the transformation is associated with the structuring element. The transformation of X by T using S is a new set Y that may be represented as a new image Y. Figure 1a shows a diagram of a morphological operation. Figure 1b shows the four structuring elements S1, S2, S3, and S4 as examples. Structuring elements and associated algorithms can be designed at will to perform specific image processing and analysis functions.

MORPHOLOGICAL OPERATIONS IN THE DIGITAL IMAGE DOMAIN

The four structuring elements of Figure 1b can be used for executing hit-or-miss transforms [3]. An algorithm associated with this operation is as follows: find matches of the structuring element on the image set X and record these matches as points in the transform domain Y using the location of the origin of the structuring element and count the points in Y. S1 is a structuring element that transforms the image into itself because each point of the image is matched by S1. Because S1 consists only of one element the origin of S1 is located at that element. This operation can be used for area measurements simply by counting points. The structuring element S2 can be used to measure the number and location of intercepts between two sets, e.g., feature set and background set. The origin of S2 is at the location of the dot. S3 can be used to determine connectivity within the image set X. The origin of S3 is identified by the two pointers indicating the lower element on the right of the structuring element. S4 can be used to measure cord lengths of the image. The origin of the structuring element is located at the center as indicated by the pointer.

Figure 2 shows an example of a morphological operation in "slow motion." The lower line of arrays represents the image set, the center line the structuring element, and the upper line the step by step transformation of the image set into the transformed set. Each time the structuring element matches a corresponding configuration of the image, a "hit" point is recorded in the transform set domain. The steps 1, 3, and 6 result in hits. The steps 2, 4, 5, and 7 result in misses.

Figure 3 shows four morphological operations of the hit-or-miss transform type. The array at the upper left of Figure 3 represents the image set. The next column shows the structuring elements of the hit-or-miss transform, and the column to the right represents the transformation of the image set into the transformed sets. The left and right intercept transforms extract the left and right border elements of the image. The four and nine connectivity operations measure the number and location of blocks of four and nine elements. The cord length of four operation measures the number and locations of cords of the length of four elements in the image. There is only one match or hit in the example. Similarily, gap or covariance operations can be performed that measure empty areas of the image set. The operations dilation and erosion are defined as follows [1, 2]:

The dilation of X by S produces a set of elements y that are members of a set Y such that y is the vector addition of x and s, where the x's are members of the image set X and the s's are members of the set S of the structuring element. In notation:

$$X \oplus S = \{y \in Y \mid y = x + s \text{ for some } x \in X \text{ and } s \in S\}$$

The erosion of X by S is the set of all elements x such that $x + s \in X$ for every $s \in S$. In notation:

$$X \ominus S = \{x \in Y \mid x + s \in X \text{ for every } s \in S\}$$

Figure 4a shows an example of the dilation operation. The image set is designated by X and the transformed set is designated by Y. The structuring element is located between X and Y. Dilation adds elements to the image set. Figure 4b shows an example of the erosion operation. Erosion subtracts elements from the image set. The dilation operation can be used to smoothen the boundaries and fill gaps of the digital feature image. This process may enhance features so that they can be matched better against a model. Erosion can be used to process the feature into its skeletal structure which also can be used for feature extraction purposes. Figure 5 shows a preprocessed binary radar image of an airport. Figures 6 and 7 show the dilation and erosion of Figure 5, respectively. The structuring element for these operations has the form of a three by three array with the origin at the upper left corner element and three diagonal dots from the upper left to the lower right.

Figure 8 shows a portion (20 by 20 pixels) of a digital image that contains a horizontal road. The numbers represent digitized gray-tone values of the pixels. The structuring element that is used for the morphological operation performs two functions. First, it computes the difference of two elements of a column. The distance d between the two elements can be selected. Second, it transforms the differences that are equal or smaller than a number n into zero, and all differences larger than n into one. The number n can be arbitrarily selected. Figure 9 shows the transform of Figure 8 with d equal to one and n equal to ten.

DISCUSSION

Digital morphology is not limited to a few operations. New morphological operation can be invented to meet special measurement and analysis requirements. Digital images of features can be thought to consist of image primitives, attributes, descriptors and descriptor sets organized into a hierarchical architecture. There is a close

relationship between the hierarchical architecture of feature images, feature vectors (used in pattern recognition), and image feature sets [4, 5]. Morphological operations deal with the transformation of image sets and, thus, provide powerful tools for automated feature extraction. Because digital morphology uses adding, subtracting, matching, thresholding and other simple decision processes, it is less computationally intensive than other processes such as statistical methods, convolutions, or Fourier transforms. Digital morphology will not replace other image processing techniques because automated feature extraction will require the combination of many techniques.

CONCLUSION

It is concluded that:

1. Digital morphology provides new tools for automated feature extraction.

2. Morphological operations can be designed to perform specific measurement and analysis functions on the digitized pixel structures of feature images.

3. Morphological operations are less computationally intensive than most other image processing techniques.

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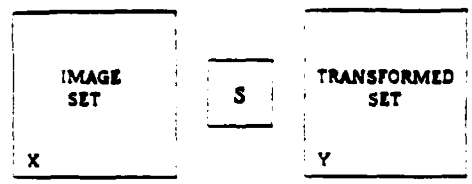

FIGURE 1a. DIAGRAM OF MORPHOLOGICAL OPERATION

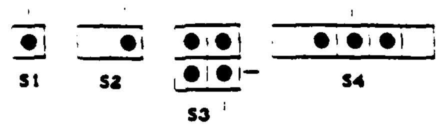

FIGURE 1b. EXAMPLES OF STRUCTURING ELEMENTS

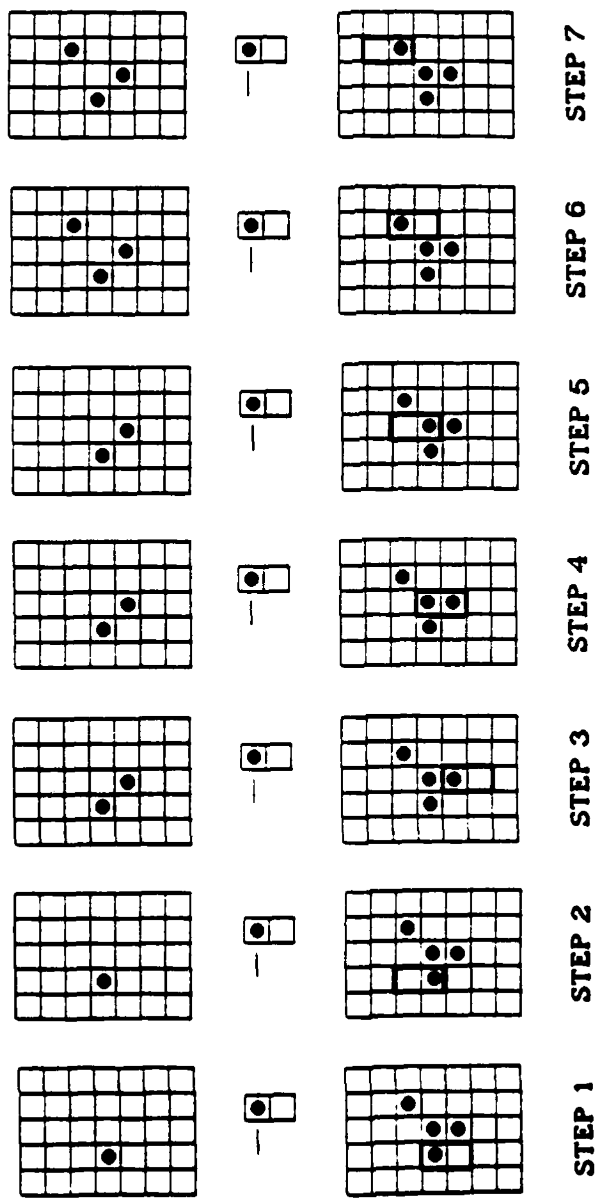

FIGURE 2. EXAMPLE OF A MORPHOLOGICAL OPERATION

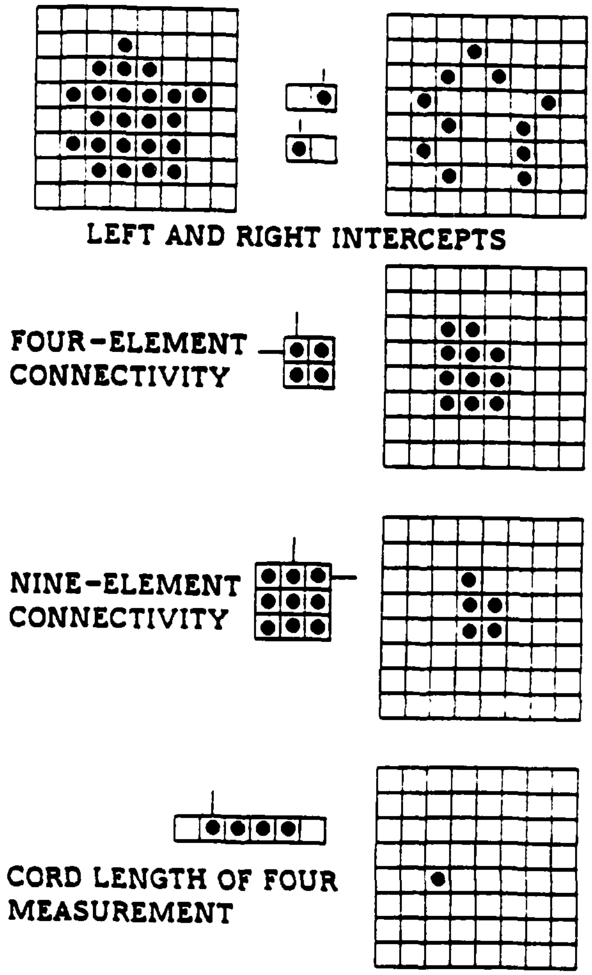

FIGURE 3. INTERCEPT, CONNECTIVITY AND CORD LENGTH OPERATION

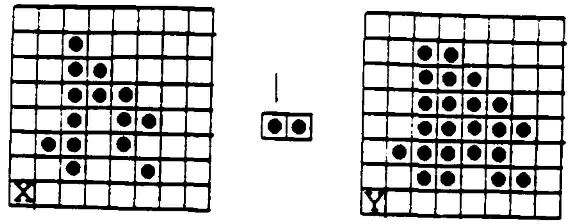

FIGURE 4a. DILATION

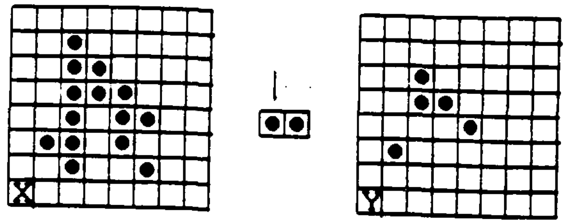

FIGURE 4b. EROSION

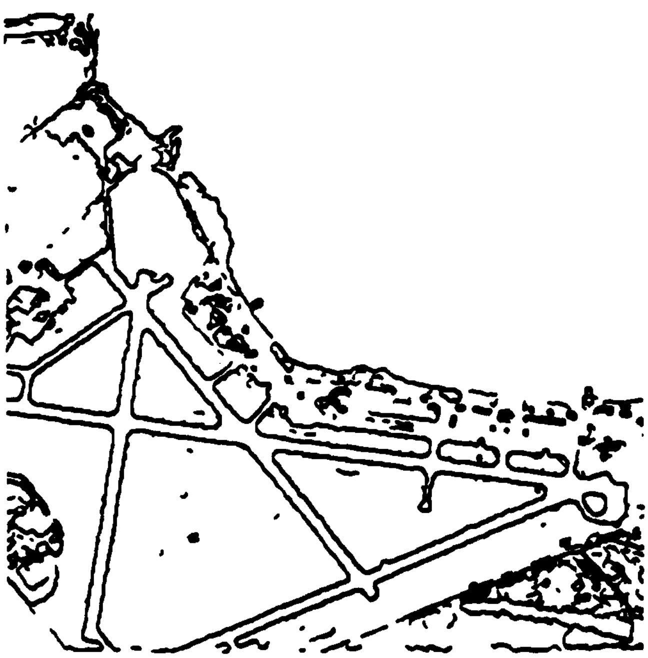

FIGURE 5. BINARY RADAR IMAGE OF AIRPORT

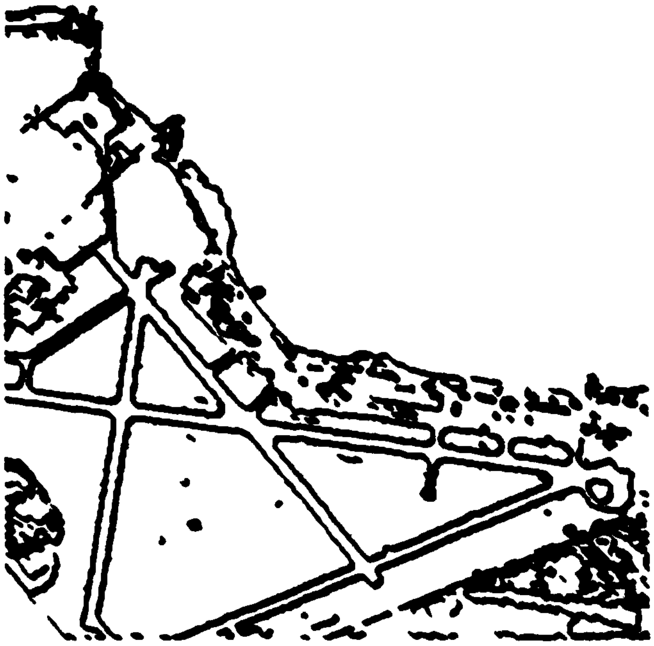

FIGURE 6. DILATION OF FIGURE 5

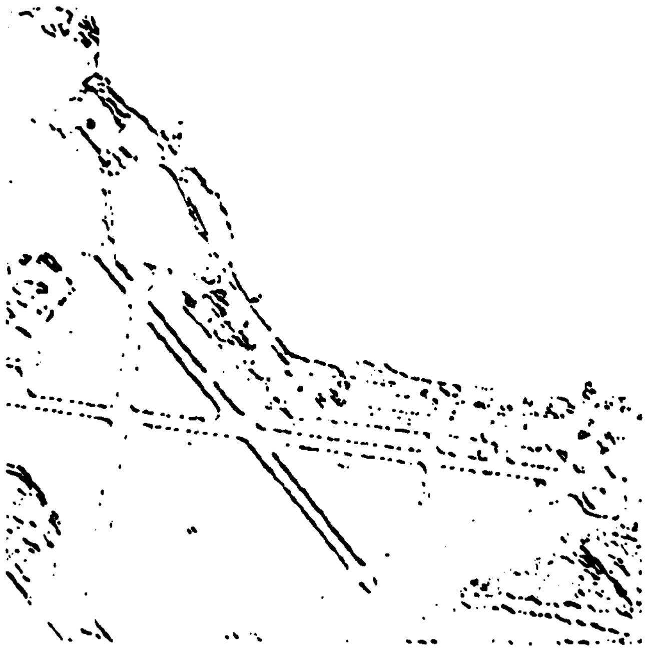

FIGURE 7. EROSION OF FIGURE 5

47	53	49	52	51	47	44	52	48	51	44	48	52	54	51	48	49	51	47	51
54	53	54	52	45	48	48	53	48	49	52	49	53	48	52	53	50	44	44	51
52	45	52	44	47	49	50	53	44	44	54	53	51	54	49	52	51	46	47	52
46	44	47	44	45	52	50	45	51	47	45	54	48	48	44	46	50	47	45	48
49	52	47	47	48	50	50	44	49	52	44	46	46	50	44	52	51	50	54	53
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50	49	43	49	45	44	52	46	46	43	44	48	45	43	46	47	50	46	45	47
48	48	47	50	43	44	44	48	50	49	48	52	51	50	52	44	52	49	51	44

FIGURE 8. DIGITIZED IMAGE WITH HORIZONTAL LINE FEATURE

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE 9. TRANSFORM OF FIGURE 8

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